MAGNETIC RESONANCE IMAGING

DEFINITION

MAGNETIC RESONANCE IMAGING

- A computer-based cross-sectional imaging modality
- The use of magnetic field and radio waves to obtain a mathematically reconstructed image
- **Originally called:** Nuclear Magnetic Resonance

ADVANTAGES OF MRI

- Best low contrast resolution
    - Main advantage
    - **Rationale:**
        - X-ray attenuation coefficient in soft tissue – differ by <1% (in same tissue)
        - Spin density & T1 – differ by 20-30% (in same tissue)
        - T2 – differ by 40% (in same tissue)
- No ionizing radiation
- Direct multiplanar imaging
- No bone or air artifact
- Direct flow measurements
- Totally noninvasive
- Contrast media not required

MRI CONTRAINDICATION

- Cardiac pacemaker
- Aneurysm clips
- Claustrophobia
- Metallic fragments in the eye
- Cochlear implants
- Internal drug infusion pumps
- Neurostimulators
- Bone growth stimulators

MRI VS CONVENTIONAL RADIOGRAPHY

MRI

- Provides sectional images
- No superimposition of structures
- Clearly demonstrates structures even without contrast media
- Can resolved relatively small contrast differences among tissue
- Contrast depends on the interaction of matter with electromagnetic forces

CONVENTIONAL

- Provides "flat" image
- Structures are superimposed
- Contrast media is required to clearly distinguished one anatomic structure or organ from one another
- Limited in its ability to distinguish types of tissue
- Cannot detect small attenuation changes
- Can only distinguish air, fat, bone, soft tissue, and metal
- Contrast depends on differences of x-ray attenuation

BRIEF HISTORY

1940's

- **Felix Bloch** and **Edward Purcell** first discovered the properties of magnetic resonance
- **MRI spectroscopy:** technique they used for analysis of complex molecular structures and dynamic chemical processes

1952

- Bloch and Purcell shared a Nobel Prize in Physics

1971

- **Raymond Damadian** showed that the relaxation time of water in a tumor differed

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from the relaxation time of water in normal tissue
- Investigated excised rat tissue
- He reported that there were significant differences between normal rat tissues and tumors

1973
- **Paul Lauterbur** published the **first cross-sectional image** of objects (two water-filled capillary tubes) obtained with MRI technique

1975
- Damadian obtained the first animal images

1970s
- MRI was progressing rapidly

1978
- The first human head scans were obtained
- Followed by first human body scans

INDOMITABLE
- Original name of the first MRI machine

DEFINITION OF TERMS

ANTENNA
- Device for transmitting or receiving radio wave

ARTIFACTS
- Spurious finding in or distortion of an image

ATTENUATION
- Reduction in energy or amount of a beam of radiation when it passes through tissue or other substances

COIL
- Single or multiple loops of wire designed to produce a magnetic field from current flowing through the wire

CLAUSTROPHOBIA
- The fear of having no escape and being in closed or small spaces or rooms

CRYOGENIC
- Relating to extremely low temperature

DIFFUSION
- Spontaneous random motion of molecules in a medium

FAT SUPPRESSED IMAGES
- Fat tissue in the image is made to be of a lower, darker signal intensity

FREE INDUCTION DECAY
- Signal emitted by tissue after RF excitation

GATING
- Technique used in reducing motion artifacts

GRADIENT ECHO
- Fast pulse sequence
- Often used with 3D imaging to generate T2-weighted images

GRADIENT MAGNETIC FIELD
- A change in the intensity of a magnetic field in space
- **Unit:** mT/cm

GYROMAGNETIC RATIO
- A constant, specific ratio for each nucleus
- Half-life in MRI
- **Unit:** MHz/T
- **Hydrogen:** 43 MHz/T
    - Most abundant element in the body (60%)

INVERSE RECOVERY
- Standard pulse sequence available in most MRI imagers
- Used for T1-weighted images

LARMOR FREQUENCY

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- The frequency at which a nucleus precesses in the magnetic field
- **Unit:** MHz

MAGNETIC MOMENT

- A force created when magnetic dipole is in a magnetic field
- The inherent magnetism
- **Unit:** T

MAGNETIZATION

- The large-scale macroscopic magnetic moment resulting from many nuclear magnetic moments

NET MAGNETIZATION

- Magnetic moments of individual hydrogen nuclei aligned in the external magnetic field

PERFUSION

- Flow of blood through vessels of an organ or anatomic structure

PRECESSION

- The wobble of the rotational axis of a spinning body about a stationary axis
- Describes a cone
- **Rate of precision:** increases as MF strength increase

RADIO FREQUENCY (RF)

- Electromagnetic radiation having a frequencies from 0.3kHz to 300 GHz
- **RF range in MRI:** 1-100 MHz

RAW DATA

- Information obtained by radio reception of the MRI signal as stored by a computer

RELAXATION

- Returning to equilibrium

RELAXATION TIME

- The time required for return

RESONANCE

- Transfer of vibrating energy from one system to another

SPECIFIC ABSORPTION RATE (SAR)

- The power absorbed during RF irradiation
- **Unit:** W/kg

SPIN DENSITY (SD)

- Concentration of hydrogen nuclei in tissue
- Principal determinants of MRI signal

T_1 RELAXATION TIME

- Spin-lattice relaxation time
- Longitudinal relaxation time
- **Decrease in signal:** 63% of maximum value

T_2 RELAXATION TIME

- Spin-spin relaxation time
- Transverse relaxation time
- **Decrease in signal:** 37% of maximum value

TESLA

- SI unit of magnetic field strength
- 1T = 10,000 G

PHYSICAL PRINCIPLES

SIGNAL PRODUCTION

- MRI depends on the properties of the nucleus
- **Hydrogen nuclei:** element used in most MRI
    - **Rationale:**

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- Strongest nuclear magnets
- Create the strongest MRI signal
- Most common element in the body

PULSE SEQUENCES

SPIN ECHO SEQUENCE

- Classic imaging sequences
- Most widely use pulse suquence
- Used with timing parameters to yield T1-weighted images
- Also provide pro ton-density weighted images
- Time consuming
- Slow patient "throughput" or productivity

INVERSE RECOVERY

- A sequence that accentuates T1 information
- Time consuming
- Slow patient "throughput" or productivity

FAT SAT

- Pulse sequence used to saturate fat

FAT SUPPRESSED IMAGES

- Used to minimize the high signal intensity from fat tissue overwhelming small signal intensity in the tissue of interest

GRADIENT ECHO

- Oldest imaging sequence
- Most common type of faster imaging sequence

FAST GRADIENT ECHO

- Fast gradient imaging technique
- Good wherever there is turbulent flow

FAST SPIN-ECHO

- Known as rapid acquisition recalled echo

FLUID ATTENUATED INVERSION RECOVER (FLAIR)

- Suppresses signal from cerebrospinal fluid (CSF)
- Most applicable in the brain
  - For seizures disorders
  - For spinal cord injuries

SHORT TAU INVERSION RECOVERY

- Suppresses signal from fat

FAST SPIN-LATTICE RELAXATION RATE

- Short T1
- Produces high MRI signal in T1-weighted images

SLOW SPIN-SPIN RELAXATION RATE

- Long T2
- Produces high MRI signal in T2-weighted images

FUNDAMENTAL CONCEPTS

3 PRINCIPAL INDEPENDENT PARAMETERS

- Spin density
- T1
- T2

FUNDAMENTAL PARTICLES CHARACTERISTICS

- Charge
- Spin

CLASSIC MECHANICS

- Describes the motion of large object

QUANTUM MECHANICS

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MAGNETIC RESONANCE IMAGING

- Describes the motion of atoms and their constituents

MAGNETIC DIPOLE

- Small magnet created by the electron orbit

LARMOR EQUATION

- **Formula: $\omega = \gamma B_o$**
  - **ω** = Larmor frequency or frequency of precession (MHz)
  - **γ** = gyromagnetic ration (MHz/T)
    - constant value
  - B_o = strength of external MF (T)

RESULTS OF RF ENERGY ABSORPTION BY NUCLEI

- Nuclei will turn upside down or flip (energized or excited)
- Nuclei are caused to precess in phase

EQUILIBRIUM MAGNETIZATION VECTOR (M_0)

- Amplitude of the net magnetization vector at equilibrium
- **Factors that determine the amplitude:**
  - Spin density
  - Gyromagnetic ratio
  - Strength of the external magnetic field
- **Larger M_0:**
  - More intense MRI signal
  - Brighter MR image

FOURIER TRANSFORM

- Used to generate the spectrum of free induction decay (NMR spectrum)
- Essential to most imaging techniques

NMR PARAMETERS

PROPERTIES THAT INLUENCES IMAGE APPEARANCE

- Nuclear/spin density
- Relaxation times – T1 and T2
- Flow phenomena

SPIN DENSITY

- An indication of hydrogen concentration
- Strength of signal is proportional to the number of nuclei

T1 RELAXATION TIME

- Spins begin to precess at smaller and smaller angle (out of plane)
- The return of net magnetization along the Z axis to its normal equilibrium state
- A characteristic of tissue itself

T2 RELAXATION TIME

- Spins begin to precess out of phase with each other
- Exponential loss of signal caused by dephasing in the XY plane
- Always less than or equal to T1 relaxation time

T1-WEIGHTED IMAGES (T_1W)

- Useful for showing anatomical detail

T2-WEIGHTED IMAGES (T_2W)

- Useful for showing pathology

FLOW PHENOMENA

- **Weak MRI signals:** moving substances (e.g. blood)
- **High MRI signals:** stagnant (immobile) blood (blood clot)
  - Short T1 and long T2

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MAGNETIC RESONANCE IMAGING

IMAGING PRINCIPLES

GRADIENT MAGNETIC FIELD

- A magnetic field that changes in strength in a given direction
- The only difference between NMR spectrometer and MR imager
- **Functions:**
  - Used to localized MRI signal
  - Used for slice selection
  - Used for encoding the location of MRI signal

GRADIENT COILS

- Current-carrying coils designed to produce a desired gradient magnetic field

BACK PROJECTION RECONSTRUCTION

- The earliest and easiest to understand

2D FOURIER TRANSFORMATION

- Recently used technique
- Requires a rigorous mathematical development

MR EQUIPMENT AND IMAGES

OPERATING CONSOLE

- Used to control the computer
- **Laser or multiimage camera:** used to print the image

COMPUTER ROOM

- Houses the electronics
  - For transmitting the radiowave pulse sequences
  - For receiving and analyzing the MRI signal
- **Storage of raw data/computer-constructed images:**
  - Computer disk
    - For temporary storage
  - Magnetic tape or optical disk
    - For permanent storage and retrieval

MRI GANTRY

- Contains magnets, shim coils, gradient coils and RF transceiver coils
- **Power supply:**
  - High current power for magnet
  - Precision power for secondary coils

CT GANTRY

- Contains x-ray tube and detectors
- **Power supply:** high voltage generator

IMAGING MAGNETS

MAGNET

- Major component of MRI system

THREE GROUPS

- Permanent
- Resistive
- Superconducting

PERMANENT MAGNET

- The simplest in design and least expensive to operate
- **Material:** bricklike ceramics
  - Inexpensive
  - Easy to magnetize
  - Light weight
- **Advantages:**
  - Low capital cost
  - Low operating cost
  - Negligible fringe file
- **Disadvantages:**
  - Limited field strength (0.3 T)
  - Fixed field strength
  - Very heavy

RESISTIVE MAGNET (0.15 T)

- Magnets have finite resistance

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  - **Rationale:** conductor used in coils is not a perfect conductor
- Can be turned off but requires continuous power and water cooling
- Uses 4 large coils
- **Advantages:**
  - Low capital cost
  - Easy coil maintenance
  - Negligible fringe field
- **Disadvantages:**
  - High power consumption
  - Water cooling required
  - Significant fringe field

SUPERCONDUCTING MAGNET

- A magnet containing coils made from a superconducting **metal alloy**
- Requires no continuous power source but more difficult to maintain
- No electrical resistance
- **Dewar:** a double-walled flask of metal with vacuum between the walls
- **Uses cryogens:**
  - Cooling agents
  - Used to optimized superconductivity
  - Liquid nitrogen
    - 97 K
    - Filled in **outermost chamber**
  - Liquid helium
    - 47 K
    - Filled in **innermost chamber**
- **Advantages:**
  - High field strength (2 T)
  - High field homogeinity
  - Lower power consumption
- **Disadvantages:**
  - High capital cost
  - High cryogen cost
  - Intense fringe field

SECONDARY COILS

SHIM COILS

- 30 individual windings
- For improving the homogeneity of the main magnetic field
- Prevent degradation of image quality
- **Shimming the magnet:** the process

GRADIENT COILS

- Produces gradient magnetic field
- **3 coils:**
  - Z gradient coils – for transaxial slice
  - X gradient coils – for coronal slice
  - Y gradient coils – for sagittal slice
- **Frequency-encoding gradient:** X gradient
- **Phase-encoding gradient:** Y gradient

RF COILS/PROBE

- Transceiver coils
- Used for transmitting RF signals and/or receiving MR signal
- **RF probe/Probe Assembly:**
  - A rigid unit consisting of antenna col and support material (plastic, fiber glass, insulators)
  - **Functions:**
    - Maintain the coil in its intended shape
    - Protect the coil from damage
  - **Location:**
    - Inside the gradient coils
    - Closest to the patient

COILS

RF COILS

- Antenna of the MRI system

SURFACE COILS

- Simplest design of coil
- **Applications:** spines, shoulders, TMJs, small body parts

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- **Endocavitary Coil:**
  - Used for imaging the rectum
  - Used for imaging the wall of the cavity
- **Neurovascular Coil:**
  - Used for imaging the brain and neck

PAIRED SADDLE COIL

- Commonly used for knee imaging
- Used for X and Y gradient coils

HELMHOLTZ PAIR COIL

- Consists of two circular coils parallel to each other
- Used for Z gradient coils
- Used as RF coils for pelvis and cervical imaging

BIRD CAGE COIL

- Provides best RF homogeneity of all the RF coils
- Commonly used as transceiver coil for head imaging
- Occasionally used for extremity imaging

FACILITY DESIGN

EXAMINATION ROOM DESIGN

- Room must be shielded against
  - Radio interference
  - Fringe magnetic fields
- Only **nonmagnetic materials** are used for the structure and finish
- Must have **electric filters**
  - **Rationale:** to remove interfering frequencies
- **Plumbing:** should be **PVC or copper**
- **Polyvinyl chloride (PVC):** structural concrete slab or walls
- **Lighting:** should be **direct current**

FARADAY CAGE/RF SHIELD

- A wire-mesh shield enclosing the MR imager
- Used to attenuate extraneous sources of RF

FRINGE MAGNETIC FIELD

- Magnetic field outside the patient aperture
- Must be considered in the design of MRI facility
- **Problems in fringe MF:**
  - Can interfere with the proper operation of mechanical and electronic equipment
  - Any large mass of ferromagnetic material can distort the homogeneity of the imaging volume by interacting with fringe MF
- **Takenote:** distortion of fringe MF by a ferromagnetic object will cause a compensating distortion of the imaging volume

MR IMAGES

FACTORS INFLUENCING SPATIAL RESOLUTION	
Factors	**Effect in Spatial Resolution**
Increase slice thickness	Low
Decrease slice thickness	High
Increase data collection	High
Decrease data collection	Low
Increase MRI signal acquisition	High
Decrease MRI signal acquisition	Low
Increase MRI signal strength	High

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Decrease MRI signal strength	Low

SLICE THICKNESS

- Important in visualization of pathology
- **Large slice thickness:**
  - Provide less grainy images
  - Can't visualize small pathologic lesions
- **Small slice thickness:**
  - Provide more grainy images
  - Can visualize small pathologic lesion

CONTRAST RESOLUTION

- Low contrast resolution structures
- **Most tissues:** <1% difference
- **MR parameters and biologic tissues:** >30% difference
- **Gray and white matter:** 30-40% difference
- **Null regions:** total loss of contrast
  - **Rationale:** improper RF pulse selection

APPEARANCE OF NORMAL TISSUES			
TISSUES	**SPIN DENSITY**	**T1**	**T2**
Fat and skin	High/white	Short/white	Long/white
Bone	Low/black	Very long/black	Very long/black
White matter	High/white	Short/white	Long/gray
Gray matter	High/white	Long/gray	Long/gray
CSF	Very high/white	Very long/gray	Very long/black

EXAMINATION TIME

- Keep as short as possible
  - **Rationale:** to minimize the unsharpness caused by involuntary and voluntary motion

BIOLOGICAL HAZARDS

MRI MAGNETIC FIELDS

- Exhibit threshold dose-response relationship

THREE PHYSICAL FIELDS THAT MIGHT SUSPECT OF PRODUCING BIOLOGICAL RESPONSE

1.) Strong static magnetic field (B_0)

- **Unit:** Tesla (T)
- **Affects:**
  - Membrane permeability
  - Enzymes kinetics
  - Nerve conduction

2.) Time-varying gradient magnetic field (B_1)

- **Unit:** Tesla/second (T/s)
- **Affects:**
  - Visual phosphenes
  - Bone healing
  - Cardiac fibrillation

3.) RF emission

- **Unit:** Watts/kilogram (W/kg)
- Causes tissue heating
- **Heat:** the principal result of the interaction between RF field and tissue
- **Heating:** expressed as specific absorption rate (SAR)
  - **Unit:** W/kg

MAXIMUM PERMISSIBLE DOSE (MPD)

- Not correct for MRI

PHYSICAL HAZARDS

STRONG MAGNETIC FIELDS

- **Physical Precautions:**

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- Avoid any objects made from metal or iron inside the examination room
- Patient must be free from metallic objects even internally
- Warnings signs are necessary

QUENCHING

- The events that occur when the liquid cryogens that cool the magnet coils boil off rapidly
- **Caused:**
  - Activation of the magnet STOP button
  - A fault in the magnet itself
- **Results**
  - Helium escaping very rapidly from the cryogen bath
  - A loud bang or thundering or hissing or rushing sound with the cold gas expulsion
  - Patient asphyxiation and frostbite
- **If quench does occur:**
  - RT should evacuate immediately
  - It takes 72 hrs to ramp magnet up to full magnetic potential

CONTRAST MEDIA

- Gadolinium-containing compounds
- **Gadolinium:** a metal with paramagnetic effect
  - Lower toxicity
  - Few side effects
- **Teslascan:** a new manganese-based paramagnetic **liver contrast agent**
  - Used in detection, characterization, localization and evaluation of lesions in the liver
- Feridex: an iron oxide mixture and the **only supramagnetic contrast agents** available
  - Used to detect and diagnose liver lesions

GATING

- Technique used to organize the signal
- Technique used for improving image quality
- Used to reduce motion artifacts from the beating heart
- The moving object is "frozen" at that phase of its motion, reducing image blurring

ARTIFACTS

IMAGE ARTIFACT

- A structure not normally present but visible as a result of a limitation or malfunction in the hardware or software of MRI device

MAGIC ANGLE ARTIFACT	
Description	Increase of the T2 time; bright signal in tendons
Cause	Angle about 55^{o} to the main magnetic field
Solution	Angle not about 55^{o}

PARTIAL VOLUME ARTIFACT	
Description	Loss of contrast between two adjacent tissues
Cause	Insufficient resolution
Solution	Thinner slices

METAL ARTIFACT	
Same as	Magnetic susceptibility and clip artifact
Description	Signal dropouts; bright spots; spatial distortion
Cause	Field inhomogeneity
Solution	Remove the metal; don't take a gradient echo sequence; take a short echo time

MOTION ARTIFACT	
Same as	Phase encoded motion;

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	phase effect; instability; smearing artifacts
Description	Blurring and ghosting
Cause	Movement of the imaged object
Solution	Compensation techniques; more averages; antispasmodic

HERRINGBONE ARTIFACT	
Same as	RF noise; Interference; crisscross
Description	Static on the image
Cause	Electromagnetic emissions
Solution	Shielding; eliminate the factor of disturbance

RF OVERFLOW/DATA CLIPPING ARTIFACT	
Description	Image non-uniform
Cause	Signal too intense
Solution	Manually decrease of the receiver gain

SHADY ARTIFACT	
Description	Localized inhomogeneous brightness
Cause	Various causes
Solution	Check correct positioning; call the service

SLICE OVERLAP ARTIFACT	
Description	Slice overlap
Cause	Loss of signal
Solution	Saturation

STAIRCASE ARTIFACT	
Description	Staircase like nuance
Cause	Slices too thick; no overlapping
Solution	Overlapping slices

ALIASING ARTIFACT	
Same as	Backfolding, phase wrapping & wrap around artifacts
Description	Image wrap around
Cause	Anatomy extends out of the FOV within the plane of the image
Solution	Large FOV; oversampling; foldover suppression

ZEBRA STRIPES ARTIFACT	
Same as	Zero fill artifact
Description	Zebra stripes or other anomalies
Cause	Signal changes
Solution	Surface coil; change the sequence

ZIPPER ARTIFACT	
Same as	Star artifact
Description	Bands through image center
Cause	Hardware or software problems
Solution	Large FOV; oversampling

-THE END-

"There are no secrets to success. It is the result of preparation, hard work learning from failure"

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